

3D FEM Simulations of a shape rolling process

H.H. Wisselink* & J. Huétink

Netherlands Institute of Metals Research- University of Twente, P.O.box 217, 7500AE Enschede, The Netherlands

URL: www.nimr.nl; www.tm.wb.utwente.nl

e-mail: h.h.wisselink@wb.utwente.nl; j.huétink@wb.utwente.nl

M.H.H. van Dijk & A.J. van Leeuwen

Eldim b.v.- P.O.box 4341, 5944 ZG Arcen, The Netherlands

URL: www.eldim.nl

e-mail: m.v.dijk@eldim.nl

ABSTRACT: A finite element model has been developed for the simulation of the shape rolling of stator vanes. These simulations should support the design of rolling tools for new vane types. For the time being only straight vanes (vanes with a constant cross-section over the length) are studied. In that case the rolling process can be considered stationary and an ALE formulation is suitable to calculate the steady state. Results of simulations and experiments for a symmetrical straight vane are presented.

Key words: shape rolling, FEM, ALE

1 INTRODUCTION

ELDIM manufactures, among others, stator vanes for aero engines. One step in the production of these stator vanes is a cold shape rolling process. The thickness of a strip of sheet material is reduced to obtain the right thickness at the right position at the right cross-section of the vane. Unfortunately sometimes process redesign cycles are necessary to produce vanes within the required tight tolerances. More knowledge of this process is needed to obtain a "first time right" design of this rolling process. Therefore a finite element model has been developed to get more insight in the mechanics of this process.

2 THE SHAPE ROLLING PROCESS

2.1 The tools

The shape rolling process used for the production of stator vanes will be described in more detail here. The roll-die and die-plate (Figure 1) contain respectively the convex and concave airfoil profile of the vane. The difference with the usual shape rolling process is that only one of the tools, the roll-die, rotates and that the other part, the die-plate is fixed. Therefore the length of the final stator vane is limited. Due to the applied horizontal force the roll-die rolls over the die-plate, deforming a strip, which is clamped to the die-plate, into a vane.

The vertical force controls the vertical movement of the roll-die. The roll-die makes contact with the die-plate in case the applied vertical force is larger than the force needed to roll the vane.

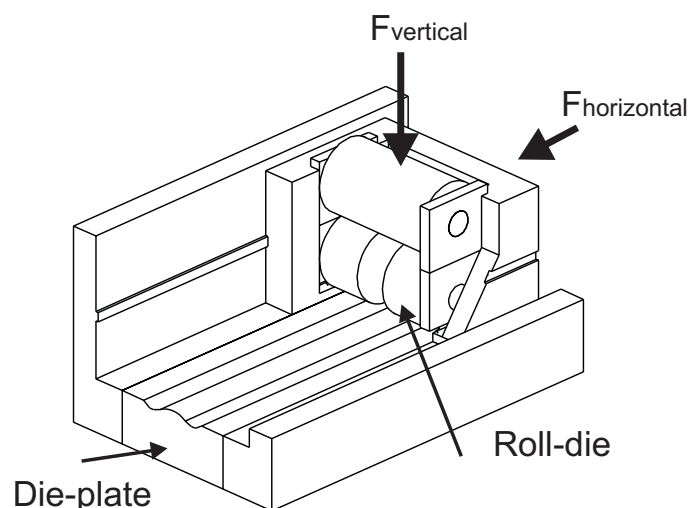


Figure 1: Tools for the rolling process.

Besides elongation, lateral spread is made possible with a gutter next to the vane profile (Figure 2). Superfluous material will be cut-off afterwards.

2.2 Investigated vane

The vane produced by the tools of Figure 2 is investigated in this paper, because experimental data are available [1] to validate the simulations. The shape of this symmetrical straight vane is almost similar to

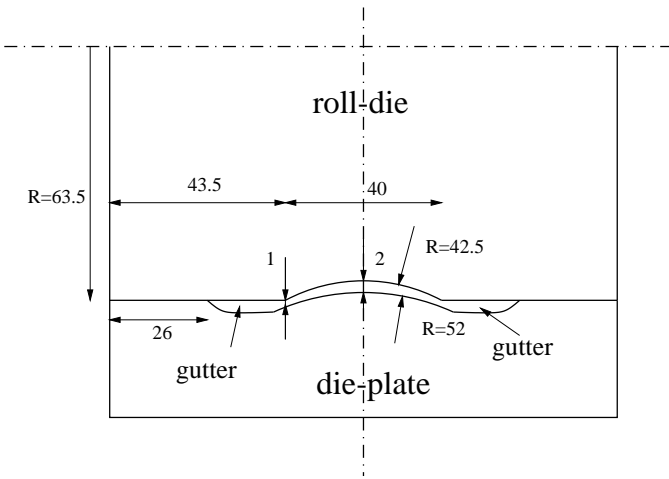


Figure 2: Dimensions [mm] of the tools used for the investigated vane.

the shape of a real vane. The vane is 2 mm thick in the middle and 1 mm thick at the leading and trailing edges.

3 FEM MODEL

The shape rolling process, described in Section 2, has been modelled with the finite element code DiekA, developed at the University of Twente.

3.1 Stationary process

The rolling of straight vanes can be considered as a stationary process, when the start and the end of the process are neglected. Therefore the rolling process can be modelled as a flow problem. Only the material in the dotted box, which moves with the same horizontal speed as the roll-die, is modelled.

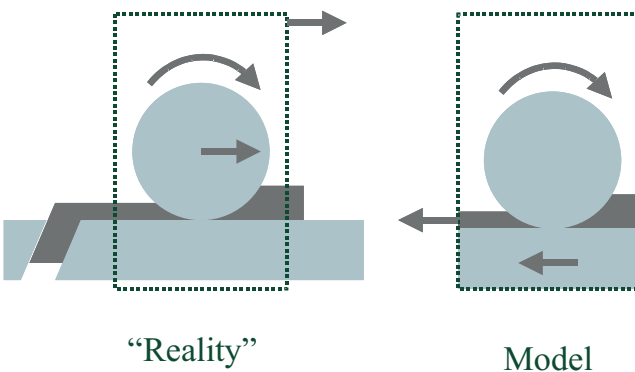


Figure 3: Kinematics of the model.

3.2 ALE method

The ALE method is an appropriate method for calculating the steady state of a stationary process, especially when dealing with free surfaces and history dependent material properties. In the ALE method it

is possible to define a grid displacement independent of the material displacements.

The geometry of the initial mesh (Figure 4) is an estimation of the expected steady state geometry. The mesh movement is kept fixed in rolling direction. The material "flows" through the mesh in rolling direction, which results in an inflow and an outflow boundary. The mesh follows the free surfaces perpendicular to the rolling direction. Internal nodes are repositioned in order to preserve a sufficient element quality.

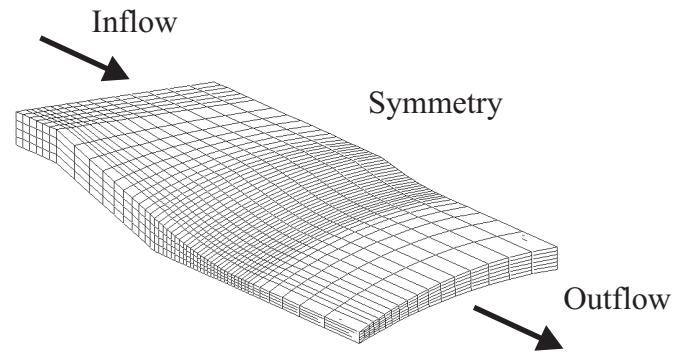


Figure 4: Initial mesh.

The simulation is continued until a steady state is reached. The final mesh is shown in Figure 5.

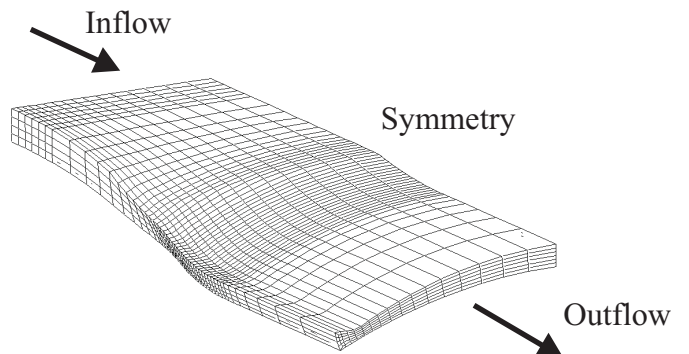


Figure 5: Steady state mesh.

The transfer of state variables is performed with a convection scheme which shows very little cross-wind diffusion [3].

3.3 Tools

Contact elements are used to describe the contact between the strip and the tools. These elements are based on a penalty formulation [2].

The tools are modelled rigid and instead of a force, the motion of the tools is prescribed. This means that the deformation and the mutual displacement of the tools is not taken into account. In practice this is an important issue, as it affects the final dimensions of the vane. Therefore this has to be incorporated in future models.

3.4 Material model

The material, which has been used for the experiments, is aluminium 6061. This material is modelled with an elasto-plastic material model with a VonMises flow rule. The hardening is described by the stress-strain curve defined in Equation 1.

$$\sigma_y(\epsilon^p) = 1 + 170(0.0261 + \epsilon^p)^{0.2} \quad [\text{MPa}] \quad (1)$$

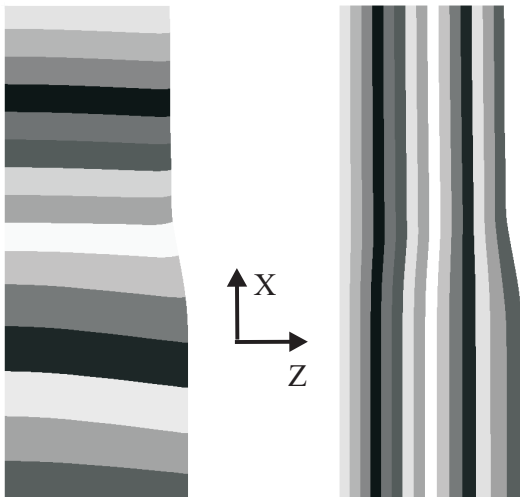
4 EXPERIMENTS

In order to get some information about the elongation and spread of the strip due to the rolling process an equidistant grid has been scratched onto the undeformed strip. The deformation of this grid is measured after rolling. An examination of the deformed grids proved that the assumption of a stationary process is valid for straight vanes, except for the start and end of the process.

5 SIMULATION RESULTS

In this section some results are shown of the simulations of the rolling of the investigated vane. The undeformed strip is 40mm wide and 3mm thick.

5.1 Deformations

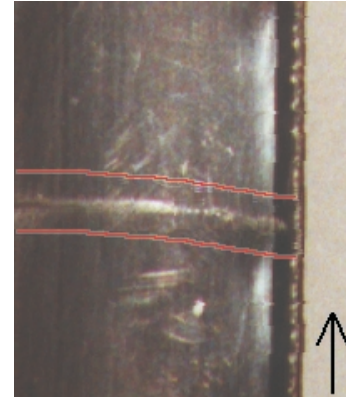


(a) \perp rolling dir. (b) rolling dir.
Figure 6: "grid-lines" from the simulation.

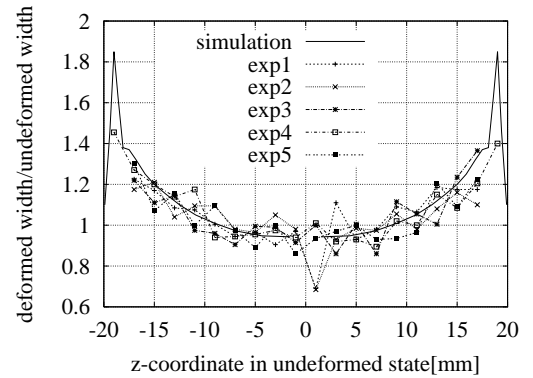
Figures 6(a) and 6(b) show lines of points having respectively an equal x-coordinate or z-coordinate in the undeformed state. These calculated lines can be compared with the measured deformations of the grid-lines on the rolled vanes. The grid-lines from the simulation in Figure 6(a) have the same shape as the

lines in the photograph of a deformed vane, presented in Figure 7(a).

Figure 7(b) gives the ratio of the distance between two grid-lines in rolling direction before and after rolling taken from the simulation and five different experiments. It can be seen that the width between two grid-lines increases at the edges, but decreases in the middle of the vane ($z = 0$). The results of the simulations agree well with the trends found in the experiments. The same phenomenon can be observed in Figure 6(b); a part of the material flows towards the center.



(a) grid-lines \perp rolling dir.



(b) Deformation \perp to rolling dir.

Figure 7: Comparison between experiments and simulation.

The equivalent plastic strain distribution is given in Figure 8. The largest values are found at the locations with the largest thickness reduction.

5.2 Contact stresses

Figure 9 gives the stresses in the contact elements used to describe the interaction between the sheet and the tools. The location where the shear stresses change sign coincides with the position of the highest normal stress. Two neutral lines can be seen, one in rolling direction and one perpendicular to the rolling direction. The maximum hydrostatic pressure in the

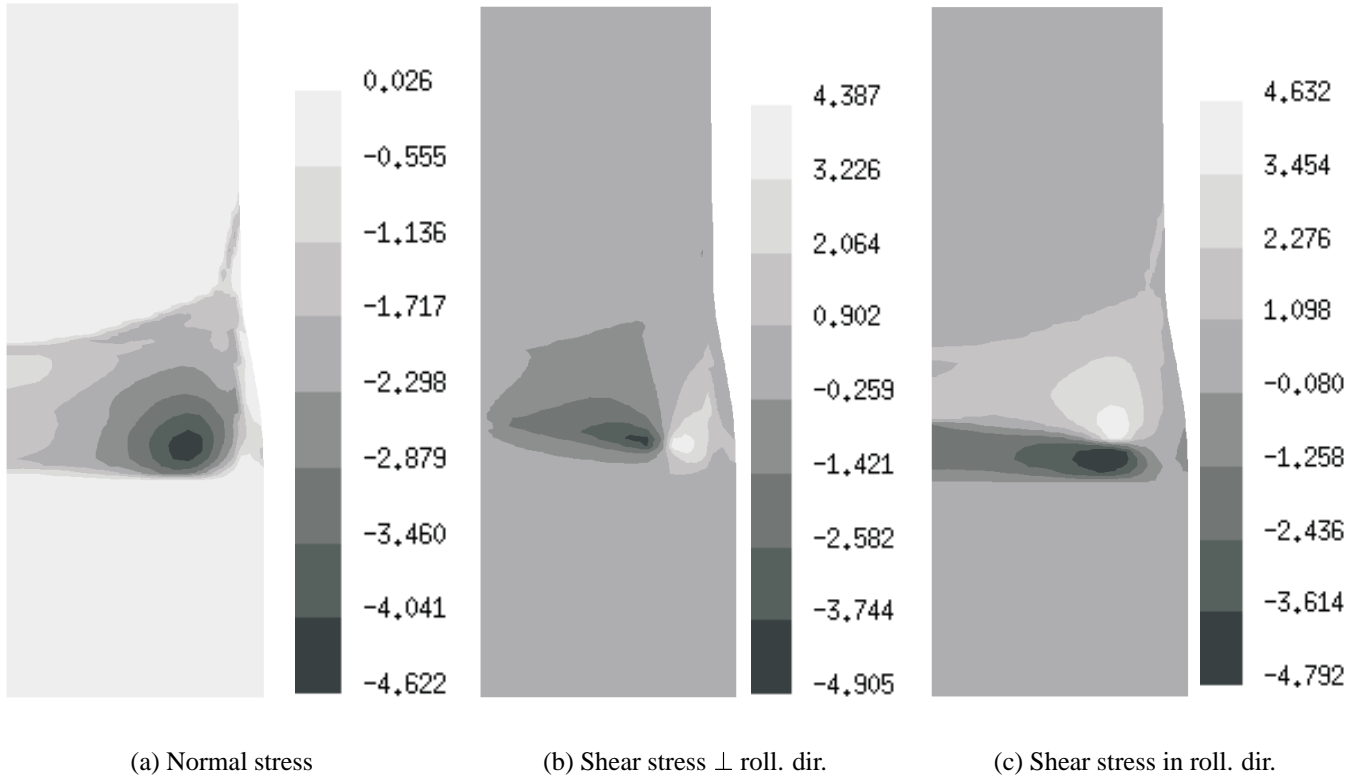


Figure 9: Normal [$\times 100$ N/mm] and shear [$\times 10$ N/mm] stresses in the contact elements between the roll-die and the vane ($\mu = 0.11$).

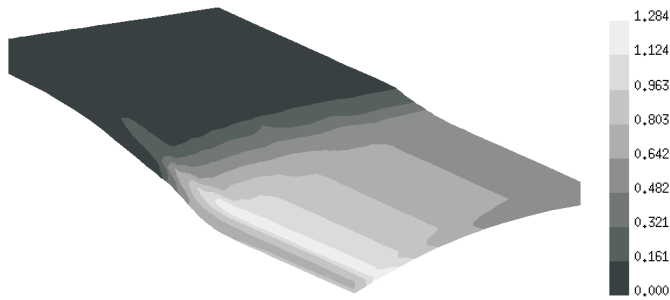


Figure 8: Equivalent plastic strain.

vane is found at the same position as the maximum normal contact stress. The position of the maximum hydrostatic pressure determines whether the material flows inwards or outwards to the gutter (See also Figure 6(b)). The maximum hydrostatic pressure increases with increasing friction coefficient.

5.3 Variation of strip width and thickness

With the current model the influence of the dimensions of the undeformed strip on the rolling process is studied. In this way the elongation/spread ratios can be determined. Furthermore the minimal strip thickness needed for a completely filled die can be found.

6 CONCLUSIONS

A finite element model has been build to simulate the rolling of straight stator vanes. The ALE method is a

suitable formulation for these kind of processes. The results correspond well with the trends of the experimental data. Therefore this model increases the understanding of this process.

In future work the model will be extended to the rolling of straight vanes with a real airfoil shape. Also the deformation of the tools has to be incorporated in the model.

ACKNOWLEDGEMENTS

The authors would like to thank A.Z. Abée for his contribution to this project.

References

- [1] A. Z. Abée. Rolling along the river. Technical report, University of Twente, 1999.
- [2] J. Huétink, P. T. Vreede, and J. van der Lugt. The simulation of contact problems in forming processes using a mixed Eulerian-Lagrangian finite element method. In *Num. Methods in Ind. Form. Processes, Proc. NUMIFORM '89*, pages 549–554. A.A.Balkema, Rotterdam, 1989.
- [3] H.H. Wisselink. *Analysis of Guillotining and Slitting, Finite Element Simulations*. PhD thesis, University of Twente, 2000.